Theoretical overview of low X physics with eA at an EIC

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Aspects of low X physics with eA at an EIC

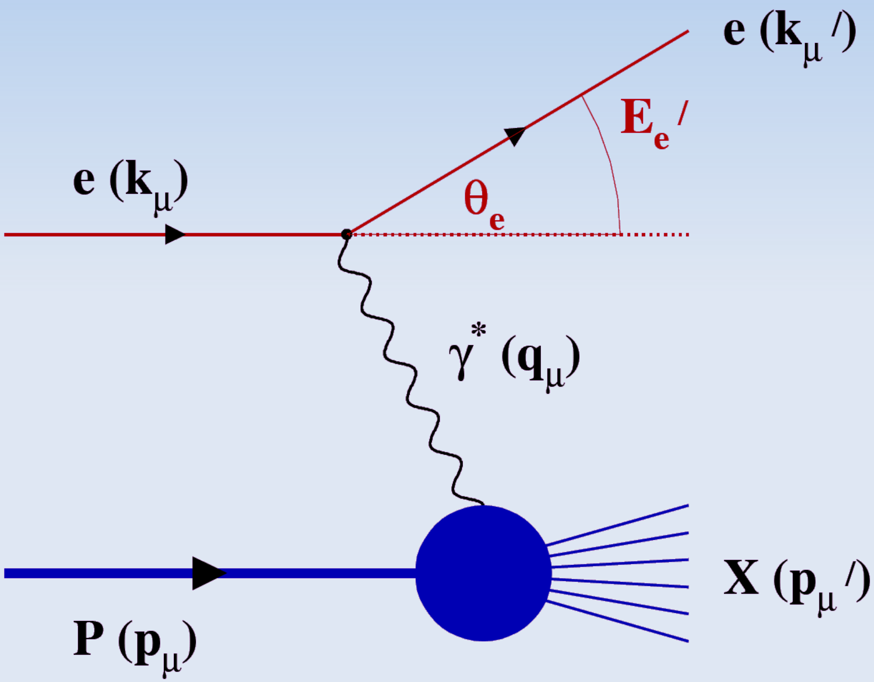
Probing extreme QCD:

unitarity, universality, strong color fields

Connection to heavy ion physics at RHIC/LHC

A hadron at small x

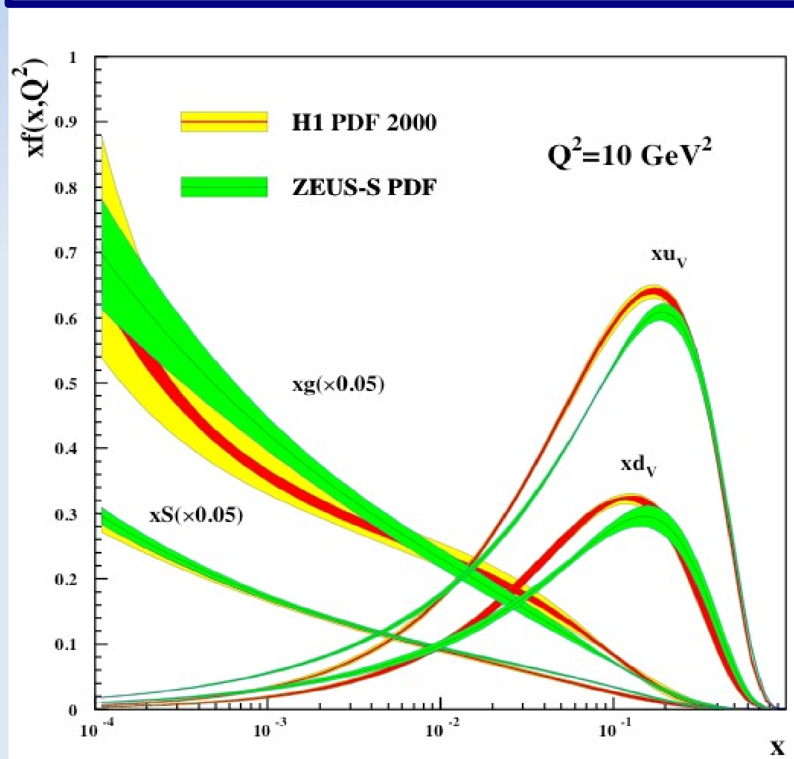
DIS: $e\,p \rightarrow e\,X$



$$x = \frac{p^+}{P^+}$$ is the fraction of hadron energy carried by a parton

HERA:

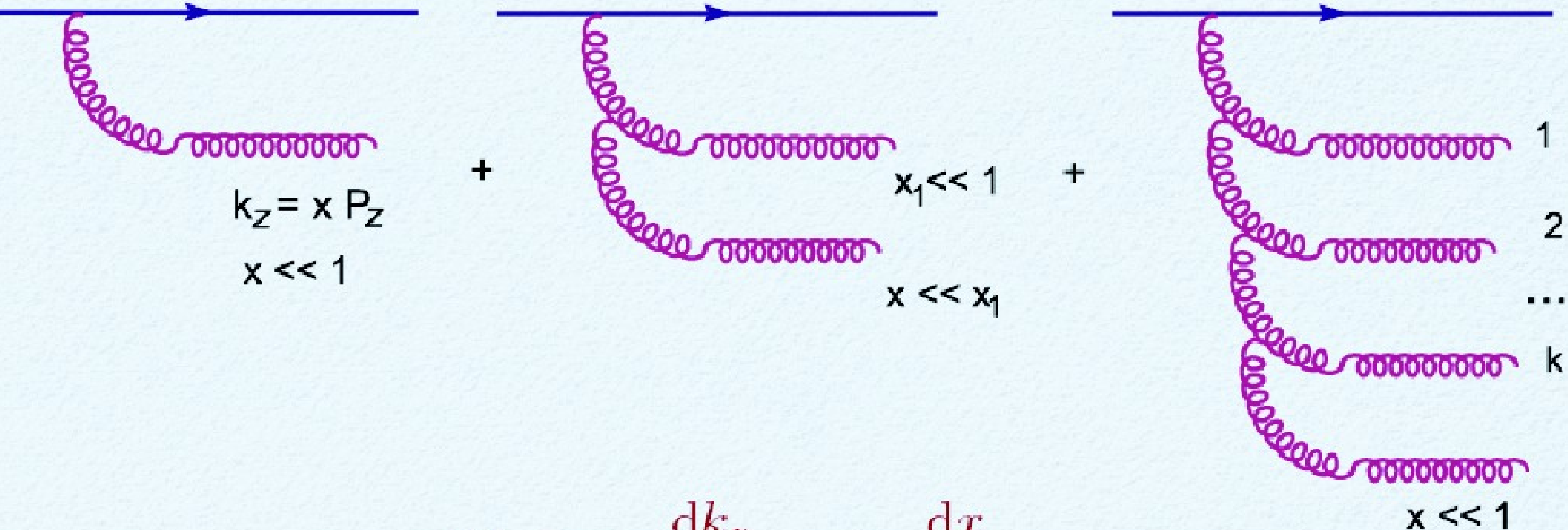
there are a lot of gluons at small x



Q2 evolution of PDF's: DGLAP

gluon radiation at small x :pQCD

The infrared sensitivity of bremsstrahlung favors the emission of 'soft' (= small–x) gluons



$$\mathrm{d}\mathcal{P} \;\propto\; \alpha_s \frac{\mathrm{d}k_z}{k_z} \;=\; \alpha_s \frac{\mathrm{d}x}{x}$$

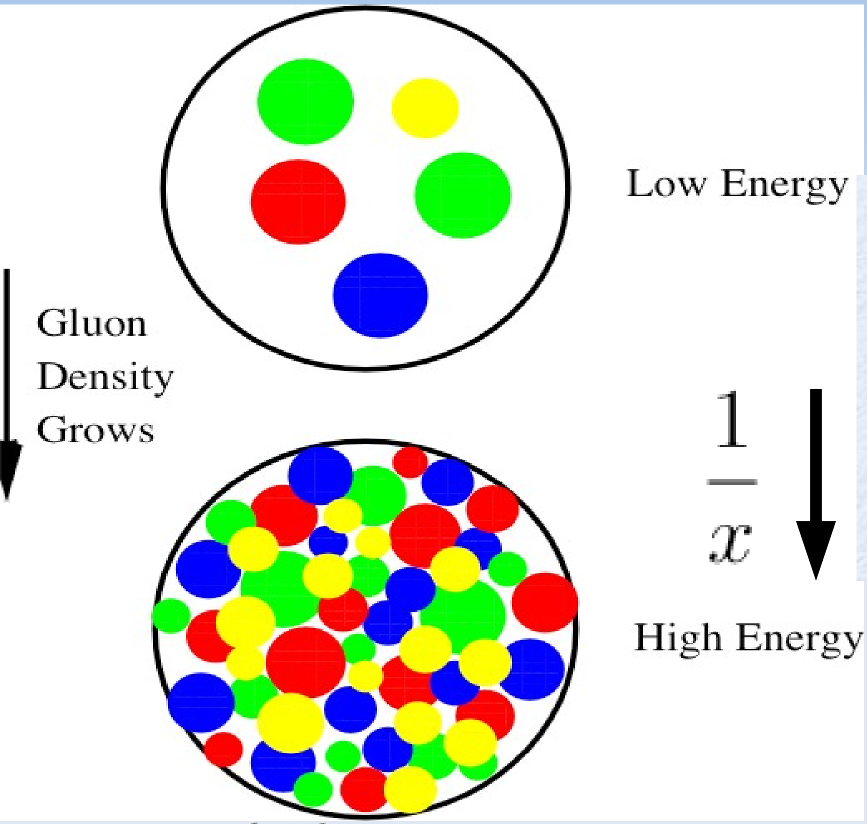
The 'price' of an additional gluon:

$$\mathcal{P}(1) \;\propto\; \alpha_s \int_x^1 \frac{\mathrm{d}x_1}{x_1} \;=\; \alpha_s \ln \frac{1}{x}$$

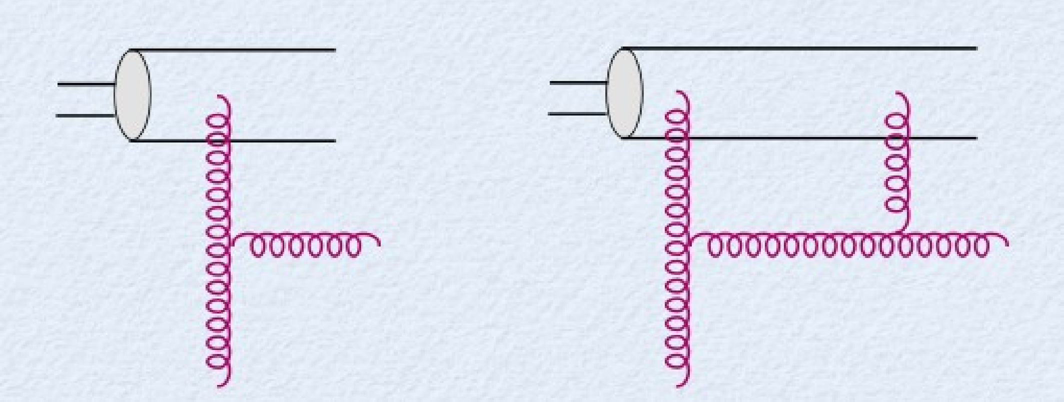
number of gluons grows fast

$$n \sim e^{\alpha_s\, ln 1/x}$$

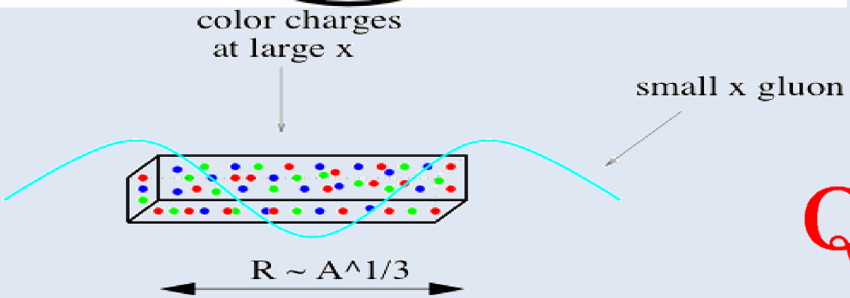
Gluon saturation



"attractive" bremsstrahlung vs. "repulsive" recombination

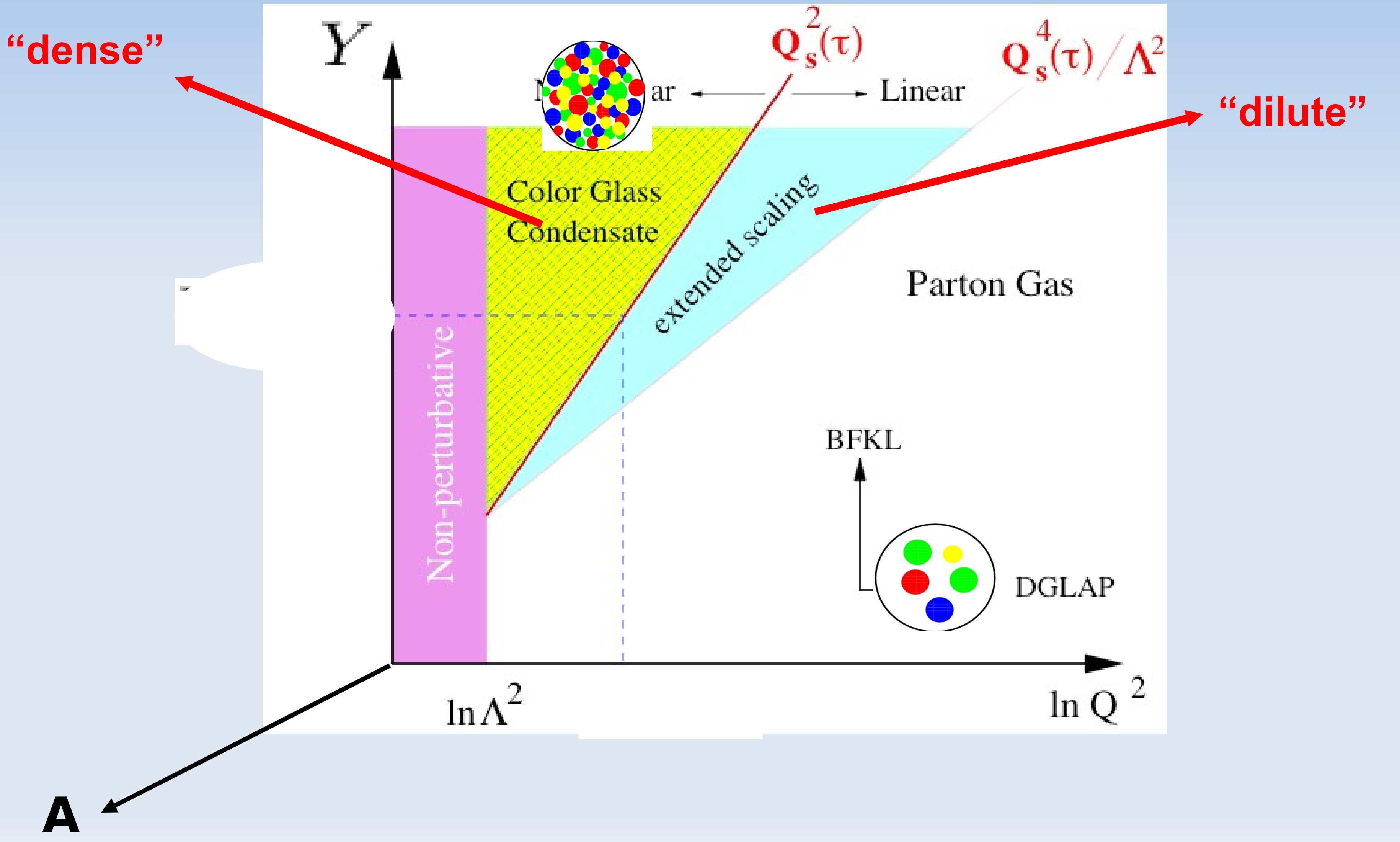


$$\frac{\alpha_s\, xG(x, b_t, Q^2)}{S_\perp\, Q^2} \sim 1$$

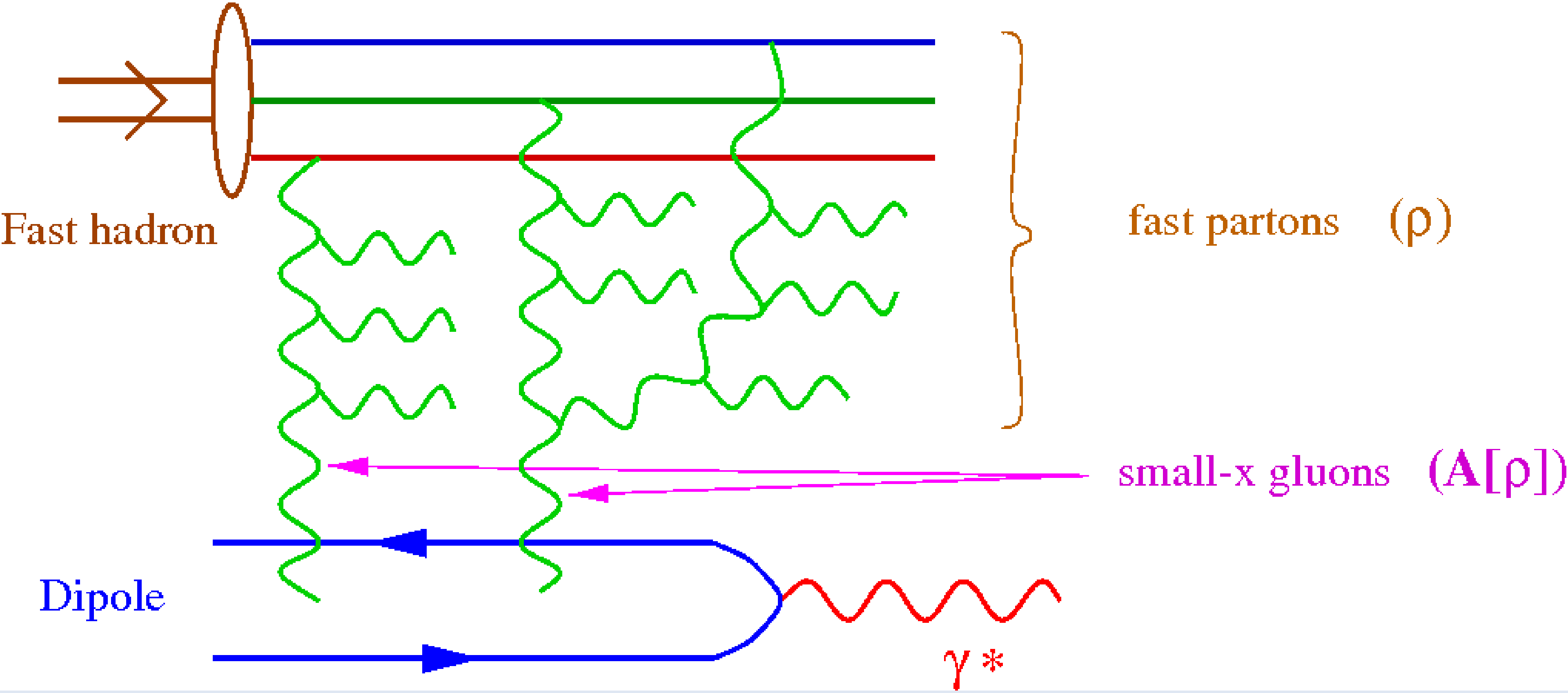


$$Q_s^2(x, b_t, A) \sim A^{1/3}\,\left(\frac{1}{x}\right)^{0.3}$$

Road Map of QCD Phase Space



DIS at small X: structure functions



$$F_2(x,Q^2) = \frac{Q^2}{4\pi^2\alpha_{em}}(\sigma_T + \sigma_L)$$

$$\sigma_{T,L} = \int d^2r\, d\alpha\ |\Psi_{T,L}(r,\alpha,Q^2)|^2\ \sigma_{dip}(x,r)$$

BK equation

$$\frac{\mathbf{d}}{\mathbf{dy}} < \mathbf{Tr V_x^\dagger V_y} >= -\frac{\bar{\alpha}_s}{2\pi} \int \mathbf{d^2 z} \frac{(\mathbf{x}-\mathbf{y})^2}{(\mathbf{x}-\mathbf{z})^2(\mathbf{y}-\mathbf{z})^2} \times$$

$$\left[< \mathbf{Tr V_x^\dagger V_y} > - \frac{1}{\mathbf{N_c}} < \mathbf{Tr V_x^\dagger V_z} > < \mathbf{Tr V_z^\dagger V_y} > \right]$$

$$\mathbf{S(y_t, z_t)} \equiv \frac{1}{\mathbf{N_c}} < \mathbf{Tr\, V_y^\dagger V_z} >$$

- Output: Modified evolution kernel:

⇒ Leading order:

$$\frac{\partial S(\underline{x}, \underline{y}; Y)}{\partial Y} = \int d^2 z \, K^{LO}(\underline{r}, \underline{r}_1, \underline{r}_2) \, [S(\underline{x}, \underline{z}) \, S(\underline{z}, \underline{y}) - S(\underline{x}, \underline{y})]$$

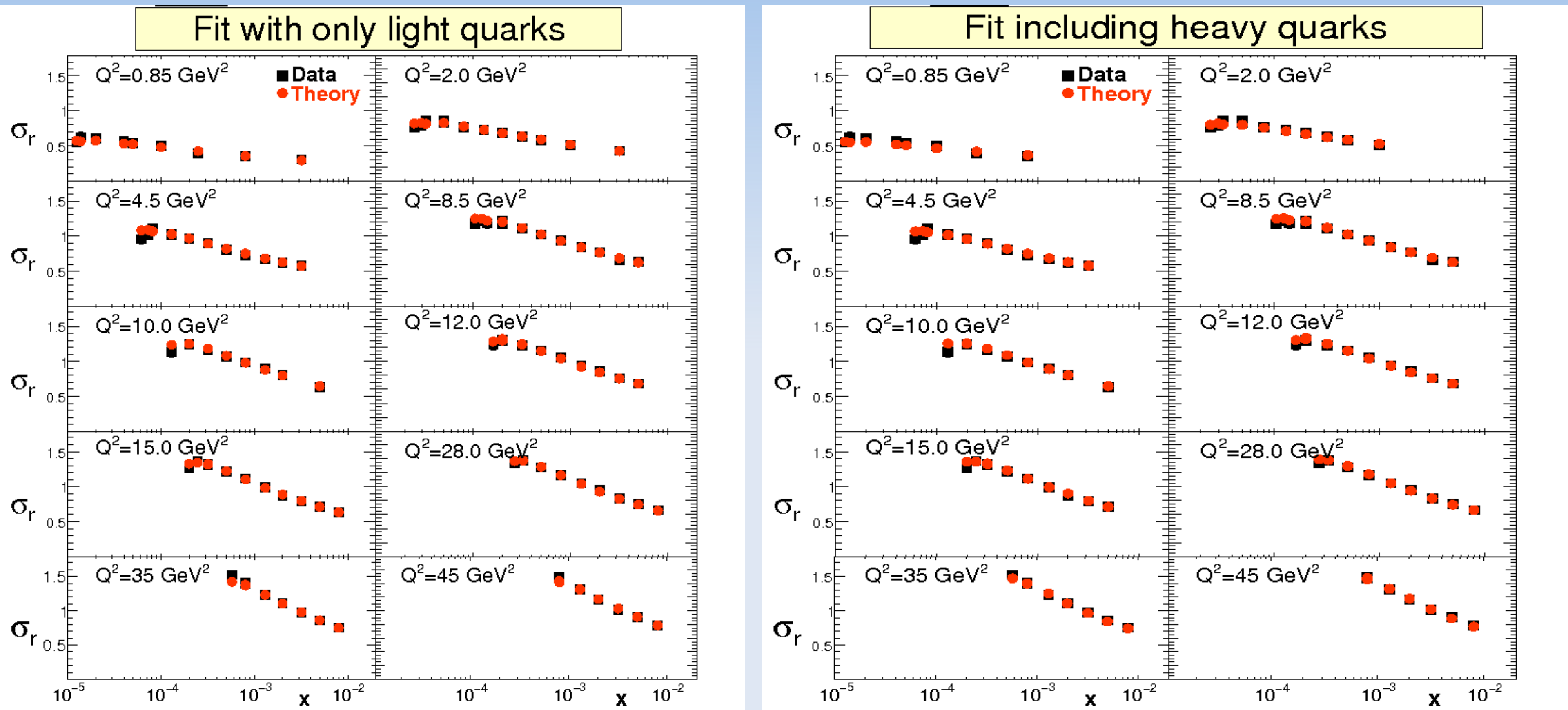
↓

⇒ Running coupling:

$$\frac{\partial S(\underline{x}, \underline{y}; Y)}{\partial Y} = \int d^2 z \, \tilde{K}(\underline{r}, \underline{r}_1, \underline{r}_2) \, [S(\underline{x}, \underline{z}) \, S(\underline{z}, \underline{y}) - S(\underline{x}, \underline{y})]$$

NLO: B-KW-G-BC (2007-2008)

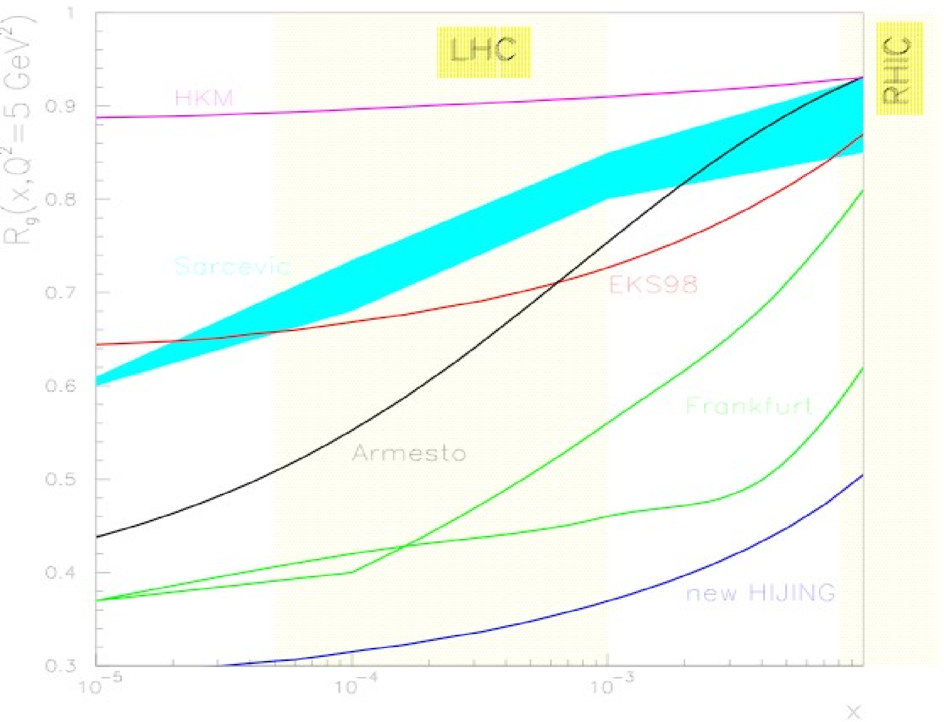
Structure functions at HERA

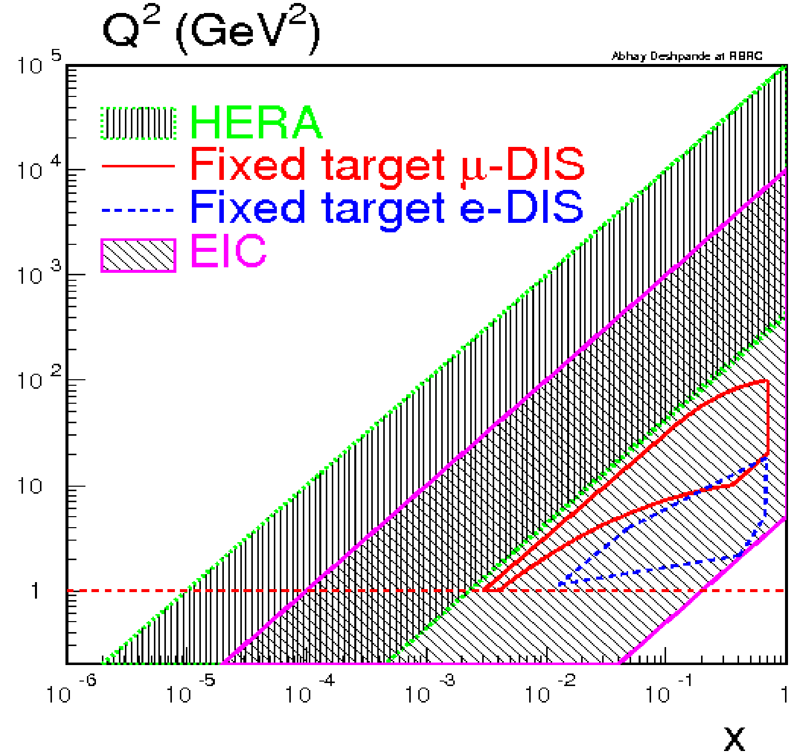


AAMQS(2010)

PQCD: DGLAP-based approaches also "work" :
need more discriminatory observables

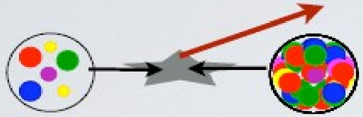
Nuclear structure functions at EIC



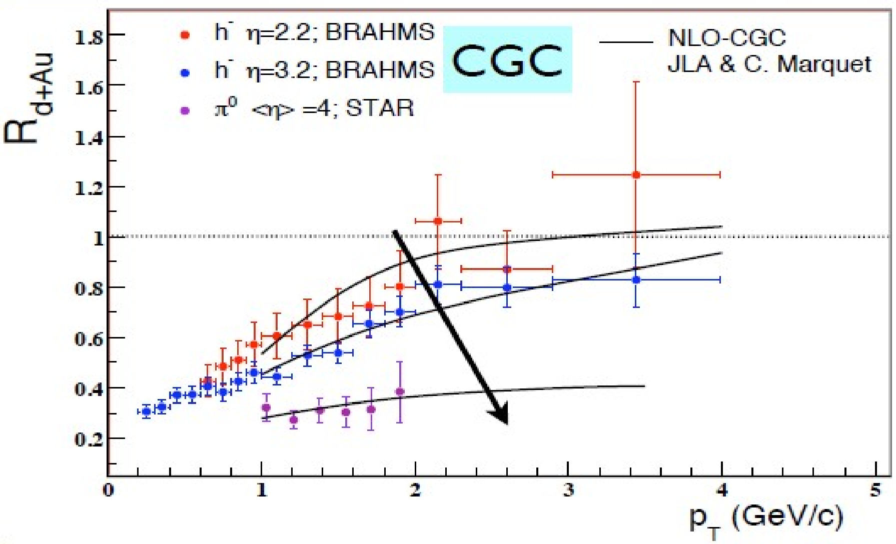


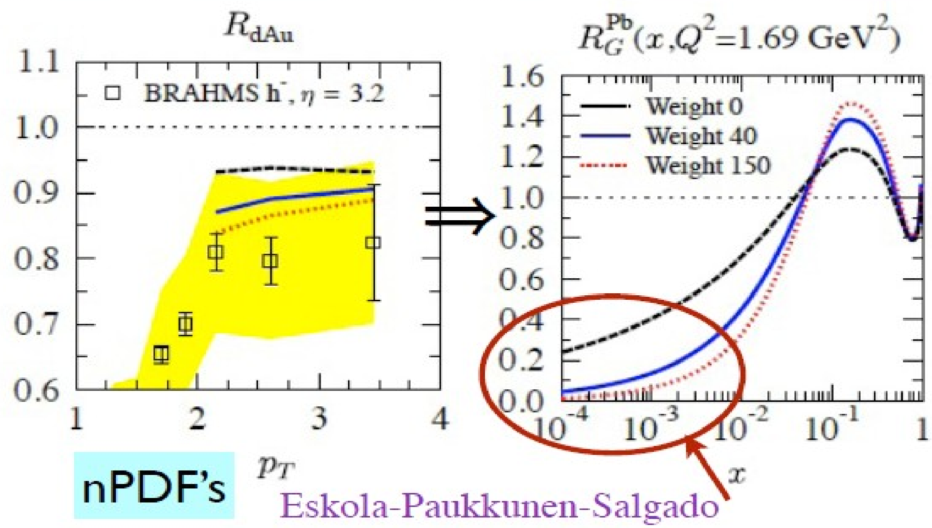
Nuclear parton (gluon) distributions are poorly known: severe consequences for RHIC/LHC

RHIC d+Au data at forward rapidity



$$x_{1(2)} \sim \frac{m_t}{\sqrt{s}} \exp(\pm y_h)$$





• Forward suppression predicted and well described in the CGC framework in terms of non-linear running coupling BK evolution

How about cold matter energy loss?

• nPDF's description of forward suppression involves a huge nuclear shadowing at small-x

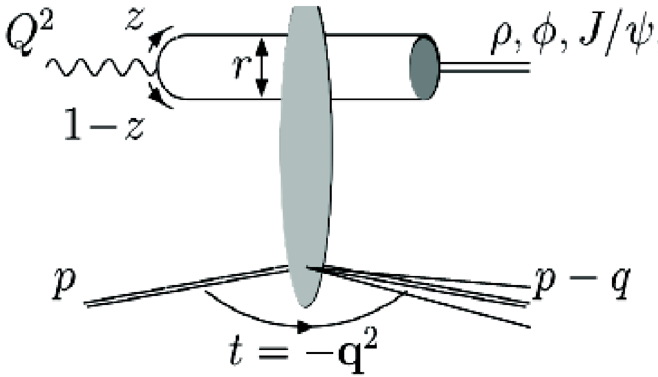
Breakdown of LT pQCD (DGLAP) ?

Diffractive structure functions: $[xg(x,Q^2)]^2$

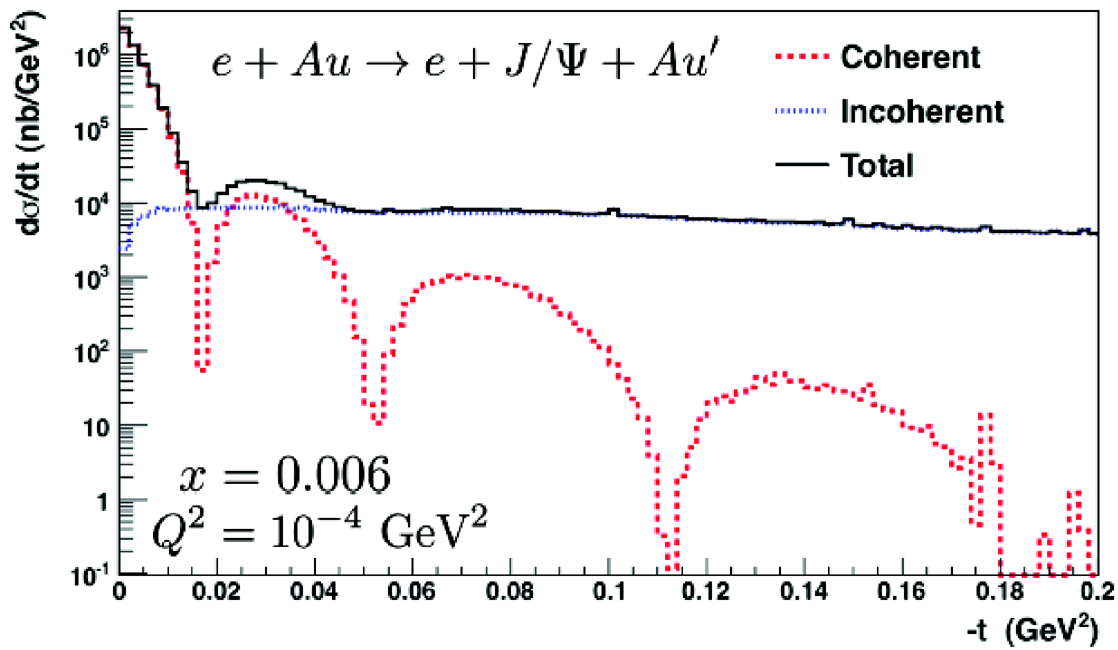
SIDIS: intrinsic gluon distribution function

Diffractive vector meson production: impact parameter dependence

Diffractive vector meson production



Toll and Ullrich (2011)



- as a function of t

exclusive production (coherent): the target undergoes elastic scattering, dominates at small |t|

→ steep exp. fall at small |t|

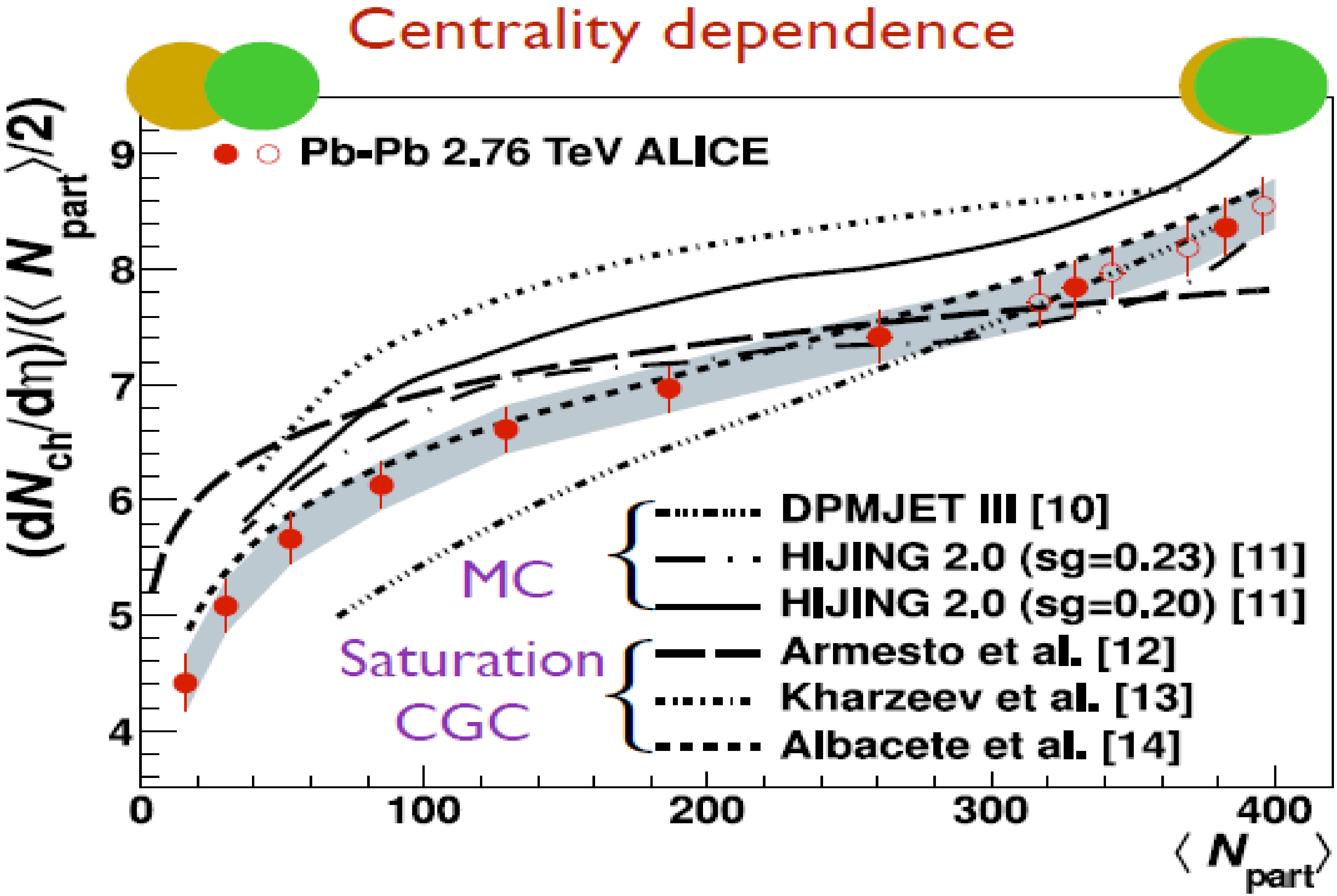
target dissociation (incoherent): the target undergoes inelastic scattering, dominates at large |t|

breakup into the nucleons
→ slower exp. fall at $0.02 < -t < 0.7$ GeV^2

breakup of the nucleons
→ power-law tail at large |t|

Fourier transform of t dependence gives the <u>impact parameter</u> profile of target

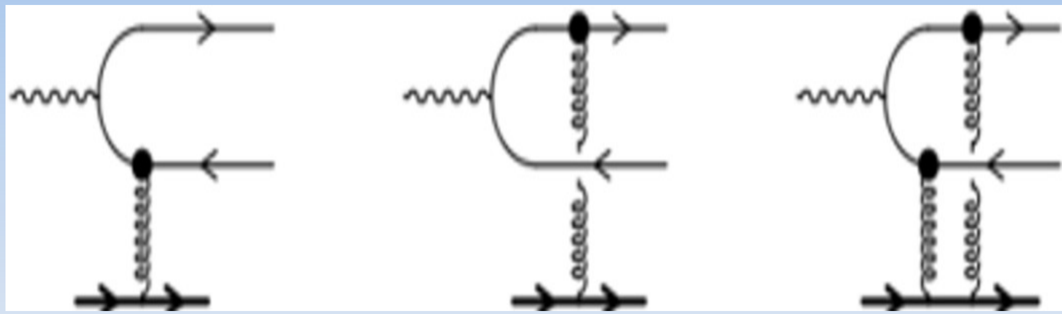
Impact parameter in AA collisions



Di-jet production: DIS

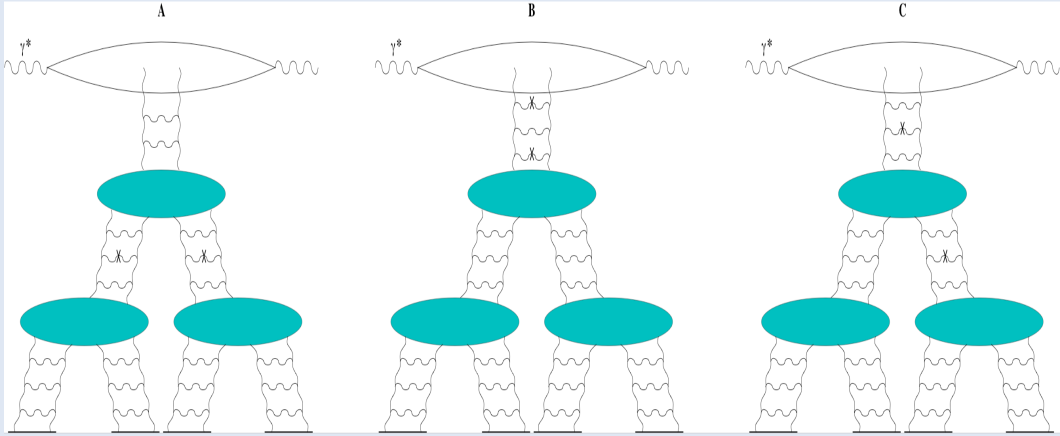
$$\gamma^\star \, \mathbf{p}(\mathbf{A}) \rightarrow \mathbf{q}\,\bar{\mathbf{q}}\,\mathbf{X}$$

FG & JJM, PRD67 (2003)
DMXY (2011)



$$\gamma^\star \, \mathbf{p}(\mathbf{A}) \rightarrow \mathbf{g}\,\mathbf{g}\,\mathbf{X}$$

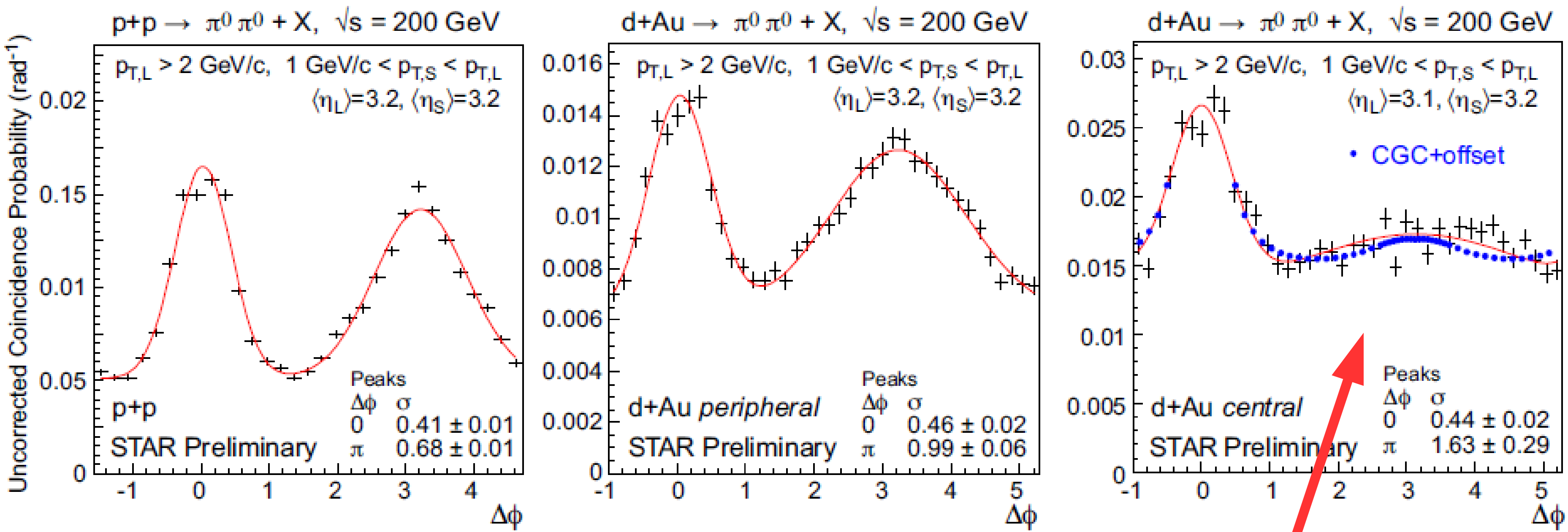
JJM & YK, PRD70 (2004)
AK & ML, JHEP (2006)



di-jet production in DIS probes multi-gluon correlations

disappearance of back to back jets

Recent STAR measurement (arXiv:1008.3989v1):

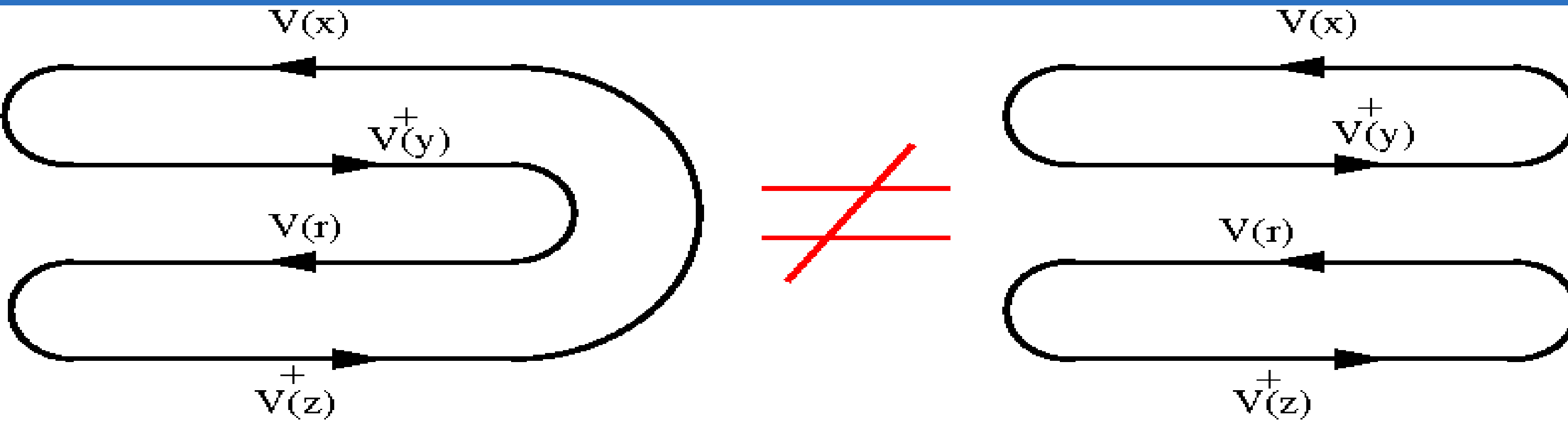


Albacete + Marquet, PRL (2010), Tuchin, NPA846 (2010)

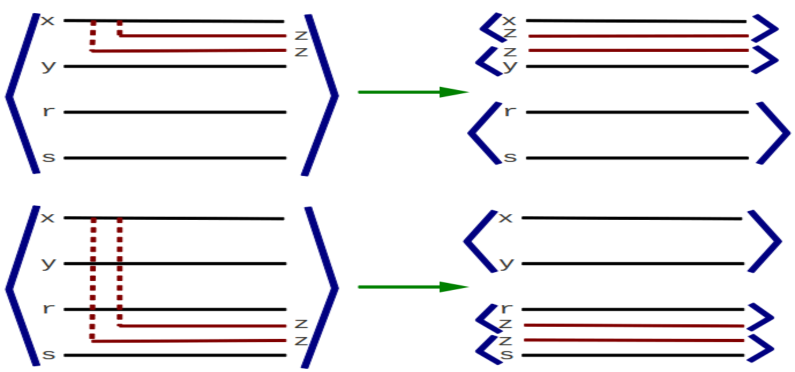
multiple soft scatterings de-correlate the hadrons

multi-gluon correlations-transverse profile of nucleus: need to go beyond single parton distributions (quadrupoles rather than dipoles)

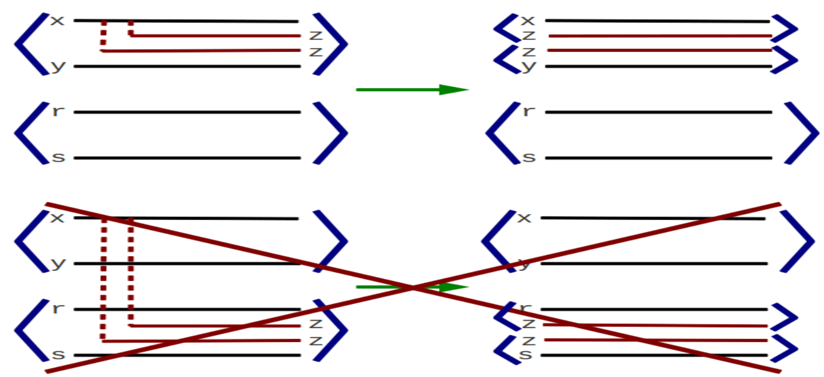
Quadrupoles vs. dipoles



and they evolve differently even at large N_c

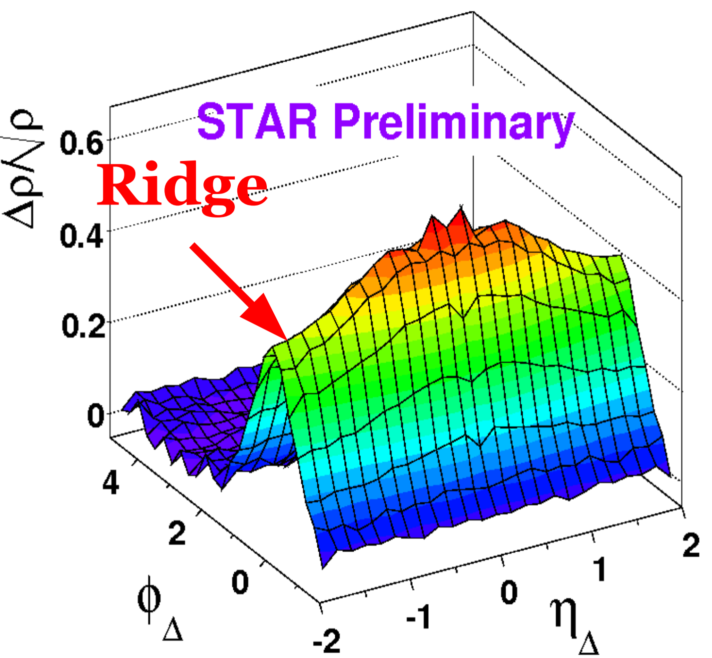


JIMWLK

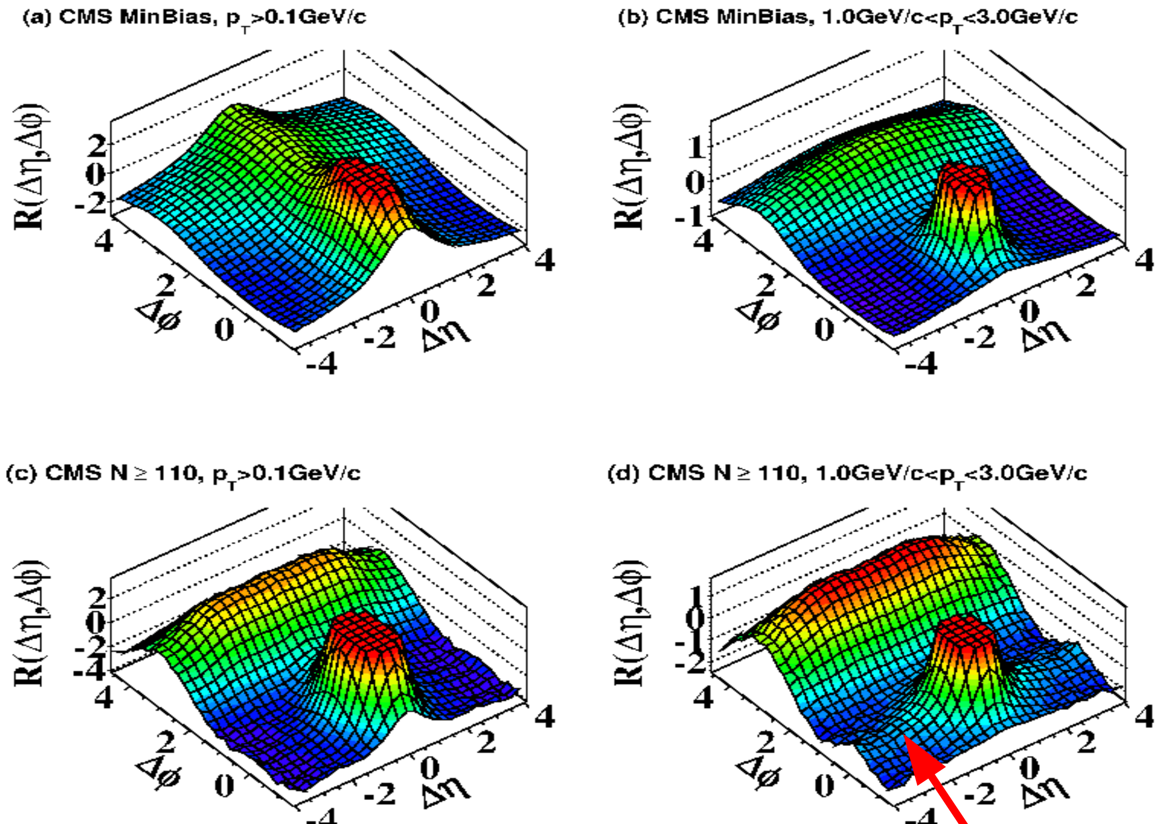


Dipole approximation

The Ridge



AA at RHIC



PP at LHC

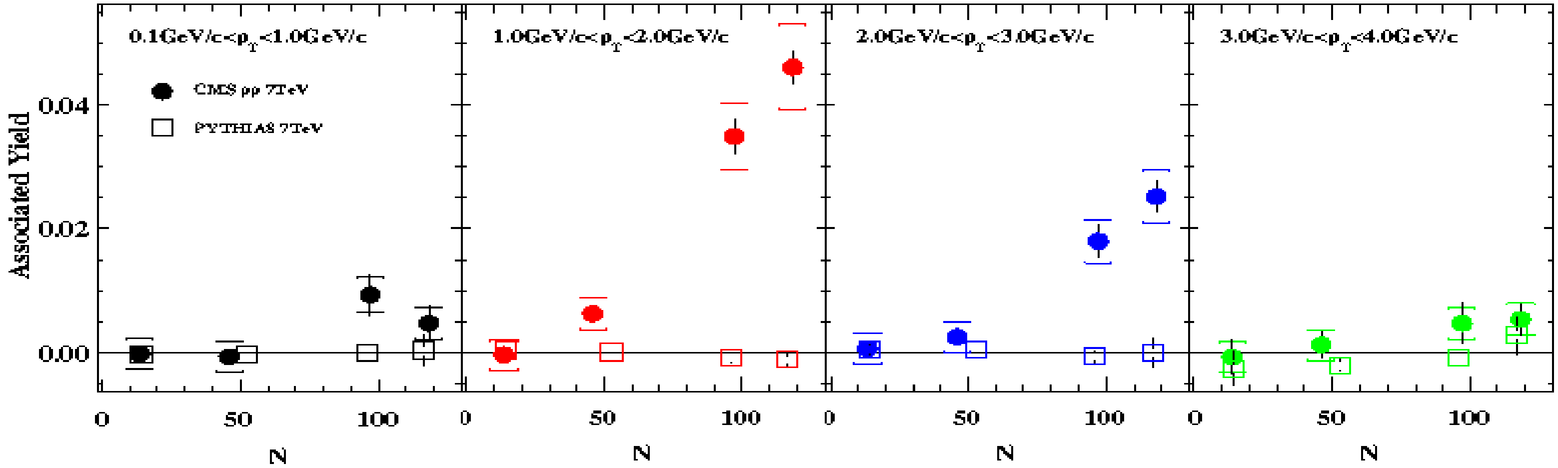
Ridge

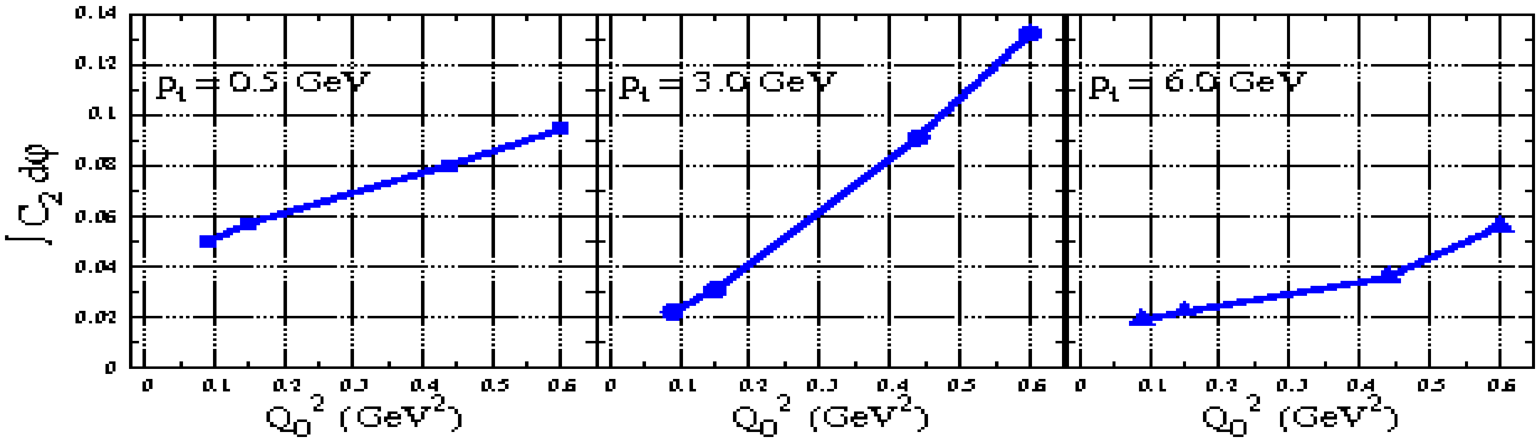
long-range rapidity correlations

multi-gluon correlations in the nucleus:

need to go beyond single parton distributions

The CMS ridge at LHC





DDGJLV, PLB697 (2011) 21

The role of initial conditions

McLerran-Venugopalan (93)

$$< \mathbf{O}(\rho) > \equiv \int \mathbf{D}[\rho]\, \mathbf{O}(\rho)\, \mathbf{W}[\rho]$$

$$\mathbf{W}[\rho] \simeq \mathbf{e}^{-\int \mathbf{d^2 x_t} \frac{\rho^{\mathbf{a}}(\mathbf{x_t})\rho^{\mathbf{a}}(\mathbf{x_t})}{\mathbf{2}\,\mu^{\mathbf{2}}}} \qquad \mu^{\mathbf{2}} \equiv \frac{\mathbf{g^2 A}}{\mathbf{S}_\perp}$$

$$\mathbf{S}(\mathbf{y_t}, \mathbf{z_t}) \equiv \frac{\mathbf{1}}{\mathbf{N_c}} < \mathbf{Tr}\, \mathbf{V}^\dagger_{\mathbf{y}}\, \mathbf{V_z} > \sim \mathbf{e}^{-\#\,(\mathbf{y_t}-\mathbf{z_t})^{\mathbf{2}}\,\mathbf{Q_s^2}}$$

how about higher order terms in ρ ?

$$\mathbf{W}[\rho] \simeq \mathbf{e}^{-\int \mathbf{d^2 x_t}\left[\frac{\rho^{\mathbf{a}}(\mathbf{x_t})\rho^{\mathbf{a}}(\mathbf{x_t})}{\mathbf{2}\,\mu^{\mathbf{2}}} - \frac{\mathbf{d^{abc}}\,\rho^{\mathbf{a}}(\mathbf{x_t})\rho^{\mathbf{b}}(\mathbf{x_t})\rho^{\mathbf{c}}(\mathbf{x_t})}{\kappa_{\mathbf{3}}} + \frac{\mathbf{F^{abcd}}\,\rho^{\mathbf{a}}(\mathbf{x_t})\rho^{\mathbf{b}}(\mathbf{x_t})\rho^{\mathbf{c}}(\mathbf{x_t})\rho^{\mathbf{d}}(\mathbf{x_t})}{\kappa_{\mathbf{4}}}\right]}$$

these higher order terms may make the spectra steeper and give leading N_c correlations (ridge)

AD+JJM+EP, in progress

Low x in eA at an EIC: extreme QCD

A new region of QCD phase space: CGC

Q_s: a dynamical semi-hard scale

multiplicities, spectra, correlations

low x physics at RHIC (forward rapidity) and LHC in pp, pA and AA collisions

EIC will enable us to probe new aspects of low x physics in nuclei with precision